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ROYAL AIRCRAFT ESTABLISHMENT

TECHNICAL REPORT 67082

ORBITAL PARAMETERS OF SAMOS 2 (1961 a1) FOR MAY-AUGUST 1963

by

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MINISTRY OF TECHNOLOGY
FARNBOROUGH HANTS

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SUMMARY

534 visual observations of the satellite Samos 2 have been used to determine its orbit at intervals of 50 nodes from 28 April-12 August 1963. The orbit was previously determined for shorter periods in 1961 and 1962. The satellite was observed over only 6% of its orbit at most, making analysis difficult. About 30% of the observations were rejected, 12% coming from three French stations.

Departmental Reference: Space 199

CONTENTS

1 INTRODUCTION

The orbit of Samos 2 (1961 α1) has been previously determined from visual observations in the summers of 1961 and 1962[1]. Samos 2 has a nearly circular orbit at a height of just over 500 km and an inclination of 97.4°, with an expected life of 15 years. The period covered in this Report is May-August 1963, and visual observations made in Europe are used.

2 OBSERVATIONS

A total of 534 visual observations, all from Europe, were used. They were taken from lists issued by World Data Centre C at the Radio and Space Research Station at Slough, and by Meudon, Besancon and Jokioinen observatories[2]. The observations were studied station by station and a breakdown of the analysis of these observations is made in Table 2. The calculated residuals in declination agree reasonably well with the estimated errors given by the observers themselves.

3 ANALYSIS OF THE OBSERVATIONS

The observations were used to determine orbital elements of the satellite at intervals of 50 revolutions, i.e. 3.2 days, from node 12400 to 14000 inclusive, with the aid of the R.A.E. orbit improvement programme[3], in its modified form[4], on a Pegasus computer. The observations were taken up to three days each side of the node to provide continuity. A complete description of the operation and uses of the various programmes required for orbit determination is given in Ref.7.

The orbit was determined in three stages. The first stage was to obtain an approximate set of orbital parameters using the prediction programme and the differential correction programme, the parameter n_1 being kept zero. These elements were used to evaluate the luni-solar perturbations, perturbations due to the higher zonal harmonics of the Earth's gravitational field ($J_3, J_4, \ldots J_9; J_2^2$) and the perturbations due to air drag and rotation of the upper atmosphere. Estimates of n_1, the rate of change of mean motion, were also obtained.

The differential correction programme was applied again, using estimated values of e (eccentricity) and ω (argument of perigee) from the model[8]

$$\xi = e \cos \omega = A \cos \{k(t - t_0)\}$$

$$\eta = e \sin \omega = A \sin \{k(t - t_0)\} + c/k$$

where t is time, and A, c and k are constants.

The final runs used the parameters obtained in the second run and all the non-rejected observations over a period of one and a half days on each side of the node, going up to three days each side if observations were scarce. The special facility for rejecting at low levels was used[7] until a fairly satisfactory orbit was determined.

In all these runs e (eccentricity), i (inclination) and ω (argument of perigee) were kept fixed until a good fit was obtained, and then released. n_1, the rate of change of mean motion, was kept fixed throughout with the value 76 degrees/100 days/100 days up to June 23 and the value 43 degrees/100 days/100 days from June 27 onwards. Fig.4 shows the variation of n, from which the above values were obtained.

4 THE ORBIT

The 33 sets of orbital parameters obtained are given in Table 1. The successive columns give

node number		
date		
time at the node	t_o	hours, min, sec
semi major axis	a	km
eccentricity	e	
inclination	i	degrees
R.A. of node	Ω	degrees
argument of perigee	ω	degrees
mean motion	n	degrees/100 days
	e_1	$(100 \text{ days})^{-1}$
	i_1	deg/100 days
	Ω_1	deg/100 days
	ω_1	deg/100 days
mean anomaly	M	degrees
extent of observations	D	days
standard deviation	ε	of observation of unit weight
number of observations	N	
coverage	C	percentage of orbit

Date and time in modified Julian Days.

The exact definitions of these quantities are given in previous papers[1,3,5,6]. The figures in smaller type after the values of the parameters give the standard deviation in units of the final figure quoted.

The values of eccentricity and inclination are plotted in Fig.1. The changes in inclination for this satellite during 1963 should be small, and the fact that nearly all the determinations are consistent with an inclination of 97.40° suggests that the standard deviations are realistic.

The eccentricity should exhibit an oscillation under the influence of the odd harmonics in the Earth's gravitational field, with a maximum where $\omega = 90°$ (about node 12950) and minimum where $\omega = 270°$ (about node 13850). Fig.1 shows that the values of e do undergo such an oscillation, and most of the values are consistent with a mean sinusoidal curve drawn through them.

Since the eccentricity is small, the variation of e with ω is not exactly sinusoidal[8] and can better be displayed by plotting $\xi = e \cos \omega$ against $\eta = e \sin \omega$: the resulting points should theoretically lie on a circle in the (ξ, η) plane, whose radius is the mean value of e. Fig.2 shows the values of ξ and η, together with a circle of radius 0.0056 centred at the point $\xi = 0$, $\eta = 0.0025$. The distance of the centre of the circle from the origin is determined by the values of the odd harmonics, and the most recent studies[9] suggest a value near 0.0012. Although the scatter of the points in Fig.2 is regrettably large, they do conform well to a circular pattern and are in this respect superior to the values obtained in 1961 and 1962, which are more difficult to interpret[9].

Fig.3 shows the values of the argument of perigee ω and the right ascension of the node Ω. The variations of these parameters with time should be almost linear, and Fig.3 shows that the values are nearly all consistent with a mean line drawn through them.

Fig.4 shows the values of the mean motion n. The slope of a curve drawn through the points should provide a measure of the air drag acting on the satellite. As the broken line in Fig.4 shows, the points tend to fall on two straight lines, thus implying that the drag between 28 April and 20 June was about twice as great as between 25 June and 5 August 1963. Since solar activity was low and fairly constant during 1963, the most likely explanation for this decrease in drag is the semi-annual effect. The drag on Samos 2 during 1961-2 has been analysed[10] and it was found that the air density at 500 km height in April and October was almost twice that in July, for 1961-2. Fig.4 suggests that this effect is present even more strongly in 1963, although a more detailed analysis, as in Ref.10, would be required in order to establish this conclusion.

Most of the values of n in Fig.4 would appear to be in error by less than 1 deg/100 days, though at least one of the last three values is probably in error by a greater amount.

We may conclude from Figs.1-4 that the results show no obvious biasses or anomalies, and are probably as good as can be expected when the average orbital coverage is only 4% and the average observational accuracy about 4' of arc.

5 EVALUATION OF THE OBSERVATIONS

534 observations from 30 different stations, all European, were used. During the analysis there were 70 major rejections (13%) and 79 minor rejections (15%). Major rejections are those whose residuals are greater than 16 times the expected rms value or greater than 5°; minor rejections[5] are those with residuals greater than 4σ. It is possible that a large proportion of the minor rejections may be due to errors in the orbit rather than errors in the observations.

A breakdown of the observations is given in Table 2. The first column contains the station name, followed by its Cospar number, total number of observations used, total accepted, minor rejections and major rejections. This is followed by the observers' own estimates of their angular and timing errors. From these an effective compounded declination error is calculated using the formula[2,7]

$$\sigma_{\text{dec}} = \left\{\sigma_A^2 + (0.43\ \sigma_T)^2\right\}^{\frac{1}{2}}$$

the constant 0.43 being obtained from the satellite's average angular velocity relative to an observer on the ground. The values of σ_{dec} were used to weight the observations during the differential correction programme. The rms value of declination residuals from the final runs have been calculated and headed 'after'.

It was found during analysis that most of the observations from Uppsala (Sweden) were being rejected: on investigation it was discovered that 3 different station co-ordinates were quoted. One of these gave much smaller residuals, on average, than the others, and was used throughout the final runs.

There were also a large number of major rejections (20%) from the 3 French stations. The station co-ordinate programme (Appendix A, Ref.6) was used to determine a possible station position error, but no consistent error could be found. Therefore it was concluded that the wrong satellite had been observed on several occasions.

6 CONCLUSIONS

Orbital parameters of Samos 2 have been obtained at intervals of 50 revolutions between 28 April and 12 August 1963. The results appear to be free of obvious biasses and anomalies, and the accuracy is probably as good as can ever be expected with visual observations over a very small arc of the orbit (between 0.5% and 6%). The orbital parameters obtained should be useful in studies of upper-atmosphere density and also possibly in determining the odd zonal harmonics in the geopotential.

Table 1

ORBITAL PARAMETERS OF SAMOS

Node	Date 1963		Time h m s	a	e	i	Ω	ω
12400	APRIL	28	20 56 57.0 10	6885.048 9	0.00522 36	97.38 2	-147.45 3	218.3 115
12450	MAY	2	3 57 55.8 6	6885.014 3	0.00387 33	97.49 1	-144.07 2	210.0 53
12500		5	10 58 51.2 8	6884.970 2	0.00464 70	97.40 1	-140.98 2	189.5 75
12550		8	17 59 44.8 8	6884.962 3	0.00581 85	97.40 3	-137.76 4	171.9 31
12600		12	1 00 38.6 3	6884.921 2	0.00516 33	97.39 1	-134.54 2	166.1 14
12650		15	8 01 29.5 7	6884.898 4	0.00602 75	97.40 3	-131.30 3	153.2 7
12700		18	15 02 19.3 6	6884.880 2	0.00637 83	97.41 2	-128.06 2	143.1 6
12750		21	22 03 08.3 4	6884.855 1	0.00575 44	97.37 1	-124.89 2	132.8 9
12800		25	5 03 55.2 6	6884.851 3	0.00609 65	97.40 3	-121.63 4	122.1 26
12850		28	12 04 41.1 9	6884.815 3	0.00578 107	97.42 3	-118.37 4	109.6 67
12900		31	19 05 23.8 5	6884.798 3	0.00767 52	97.43 3	-115.12 4	110.6 25
12950	JUNE	4	2 06 07.3 26	6884.774 3	0.00698 205	97.31 3	-112.03 4	98.3 194
13000		7	9 06 49.6 13	6884.762 2	0.00641 28	97.36 2	-108.75 3	86.2 131
13050		10	16 07 27.0 6	6884.757 6	0.00735 90	97.47 6	-105.41 8	84.5 110
13100		13	23 08 05.7 3	6884.724 1	0.00645 21	97.40 1	-102.25 2	65.0 51
13150		17	6 08 41.0 4	6884.704 3	0.00659 10	97.40 5	-99.02 6	66.6 44
13200		20	13 09 13.9 23	6884.694 9	0.00624 57	97.38 6	-95.87 9	70.7 223
13250		23	20 09 48.9 14	6884.685 5	0.00589 12	97.41 5	-92.57 6	52.0 195
13300		27	3 10 22.9 11	6884.664 2	0.00588 48	97.41 2	-89.33 3	31.1 133
13350		30	10 10 56.5 11	6884.660 5	0.00741 154	97.44 9	-86.05 11	0.9 109
13400	JULY	3	17 11 25.6 9	6884.660 7	0.00552 78	97.72 11	-82.46 15	5.8 74
13450		7	0 11 56.8 6	6884.642 3	0.00464 69	97.43 2	-79.61 3	-0.8 58
13500		10	7 12 27.9 3	6884.627 2	0.00496 34	97.39 2	-76.42 2	-17.5 13
13550		13	14 12 57.6 2	6884.617 1	0.00434 29	97.37 1	-73.22 1	-29.6 8
13600		16	21 13 28.5 2	6884.614 2	0.00630 25	97.45 2	-69.89 3	-42.5 4
13650		20	4 13 57.0 8	6884.605 3	0.00395 93	97.34 2	-66.79 3	-59.8 64
13700		23	11 14 26.5 5	6884.598 2	0.00374 49	97.41 3	-63.49 4	-76.8 60
13750		26	18 14 57.3 5	6884.578 2	0.00530 43	97.42 2	-60.23 2	-73.1 42
13800		30	1 15 25.0 4	6884.574 2	0.00442 21	97.35 2	-57.09 2	-98.8 58
13850	AUGUST	2	8 15 55.3 4	6884.559 1	0.00489 20	97.36 2	-53.85 2	-92.5 46
13900		5	15 16 23.6 6	6884.546 7	0.00563 44	97.39 3	-50.59 5	-93.7 67
13950		8	22 16 50.5 6	6884.552 4	0.00454 5	97.41 2	-47.33 4	-117.4 75
14000		12	5 17 16.1 3	6884.513 1	0.00514 14	97.36 2	-44.19 2	-148.0 26

A

Table 1

ARAMETERS OF SAMOS 2 (1961 α 1) IN 1963

Ω	ω	n	e_1	i_1	$Ω_1$	$ω_1$	M	D	s	N	C	MJD
.45 3	218.3 115	547073.5	0.0068	-0.014	0.046	-39.8	-218.6	1.0	1.0	15	4.2	38147.872882
.07 2	210.0 53	547077.5	0.0074	0.002	0.037	-21.5	-210.3	1.1	0.4	8	3.8	38151.165229
.98 2	189.5 75	547082.8	0.0076	0.021	0.021	-5.1	-189.6	4.0	1.1	12	4.6	38154.457587
.76 4	171.9 31	547083.7	0.0076	-0.002	0.018	9.6	-177.8	4.1	1.0	16	4.6	38157.749824
.54 2	166.1 14	547088.7	0.0073	-0.021	0.030	22.0	-165.9	6.0	1.0	40	5.4	38161.042113
.30 3	153.2 7	547091.4	0.0067	-0.004	0.040	32.9	-153.9	4.0	0.9	22	5.5	38164.334370
.06 2	143.1 6	547093.5	0.0059	0.031	0.025	40.9	-142.7	2.9	0.9	20	4.2	38167.626613
.89 2	132.8 9	547096.5	0.0049	0.016	-0.011	47.8	-132.3	6.0	1.1	26	5.4	38170.918861
.63 4	122.1 26	547096.9	0.0040	-0.022	0.025	52.9	-121.5	2.0	0.6	36	3.5	38174.211056
.37 4	109.6 67	547101.2	0.0027	-0.010	0.034	56.5	-108.9	2.0	0.7	17	2.3	38177.503253
.12 4	110.6 25	547103.3	0.0015	0.018	0.012	58.6	-109.8	2.0	0.5	29	2.6	38180.691248
.03 4	98.3 194	547106.2	0.0003	0.023	0.010	59.5	-97.5	5.0	0.6	6	1.3	38184.087584
.75 3	86.2 131	547107.6	0.0010	-0.001	0.012	59.0	-85.5	5.9	1.1	11	1.8	38187.379741
.41 8	84.5 110	547108.6	-0.0022	-0.023	0.027	57.3	-83.6	4.0	1.0	11	1.5	38190.671841
.25 2	65.0 51	547112.1	-0.0034	-0.004	0.032	54.2	-64.3	6.0	0.6	13	3.0	38193.963955
.02 6	66.6 44	547114.5	-0.0045	0.033	0.013	49.7	-65.9	3.0	0.6	18	3.3	38197.256019
.87 9	70.7 223	547115.7	-0.0055	0.010	0.011	43.4	-70.0	4.0	0.8	11	2.3	38200.548078
.57 6	52.0 195	547116.8	-0.0063	-0.024	0.020	37.0	-51.5	4.0	1.2	14	2.4	38203.840150
.33 3	31.1 133	547119.3	-0.0070	-0.011	0.031	25.8	-30.7	4.0	0.9	22	3.4	38207.215543
.05 11	0.9 109	547119.8	-0.0074	0.016	0.019	14.0	-0.9	4.0	0.8	8	0.7	38210.424265
.46 15	5.8 74	547119.8	-0.0076	0.002	-0.012	0.4	-5.8	1.0	0.6	15	1.7	38213.716268
.61 3	-0.8 58	547121.8	-0.0074	-0.005	0.021	-15.2	0.8	2.0	0.7	10	3.5	38217.082966
.42 2	-17.5 13	547123.7	-0.0069	-0.028	0.036	-32.5	17.4	4.0	0.9	28	3.8	38220.322523
.22 1	-29.6 8	547124.8	-0.0061	-0.003	0.030	-50.0	29.3	4.0	0.8	41	4.0	38223.592333
.89 3	-42.5 4	547125.2	-0.0049	0.031	0.013	-67.0	42.6	3.0	0.4	11	4.9	38226.884358
.79 3	-59.8 64	547126.3	-0.0034	0.003	0.022	-80.9	59.4	4.0	1.3	31	6.0	38230.176354
.49 4	-76.8 60	547127.1	-0.0015	-0.025	0.034	-89.8	76.4	5.9	1.0	25	5.5	38233.468362
.23 2	-73.1 42	547129.5	0.0004	-0.025	0.027	-92.1	72.6	3.0	0.5	39	4.3	38236.760386
.09 2	-98.8 58	547130.0	0.0023	0.013	0.018	-87.4	98.3	4.0	0.7	34	3.5	38240.052373
.85 2	-92.5 46	547131.8	0.0040	0.021	0.014	-76.4	92.0	4.0	0.8	17	4.2	38243.344390
59 5	-93.7 67	547133.4	0.0055	-0.007	0.024	-61.5	93.1	1.9	0.9	15	4.0	38246.636384
33 4	-117.4 75	547132.6	0.0065	-0.033	0.031	-44.0	116.9	4.0	0.6	21	4.1	38249.927204
19 2	-148.0 26	547137.3	0.0065	-0.001	0.015	-52.9	147.7	6.0	0.6	28	3.6	38253.220325

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Table 2

OBSERVATIONS OF SAMOS 2

Station	Cospar No.	Observations				σ_A (deg)	σ_T (sec)	σ_{dec}	
		Total	Acc.	Rej. min.	Rej. maj.			Before	After
U.K.									
Bexhill 1	2212	7	6	-	1	0.08	0.6	24	11
Cowbeech	2392	9	7	2	-	0.2	0.2	14	-
Crowborough	2373	8	5	3	-	0.09	0.15	8	5
Farnham	2265	16	10	6	-	0.08	0.15	8	5
Hanwell	2277	5	2	3	-	0.1	0.3	13	17
Newton Stewart	2312	5	4	1	-	0.7	0.9	55	20
Thames Ditton	2344	18	12	5	1	0.4	0.1	5	4
Willesden	2356	10	4	6	-	0.07	0.1	6	6
Windsor B	2358	59	42	10	7	0.1	0.6	24	12
Winkfield	2360	44	29	4	11	0.1	0.4	17	35
11 others		26	24	-	2				
FRANCE									
Meudon	3101	133	103	11	19	0.033	0.1	3	3
Besancon	3102	50	33	5	12	0.033	0.1	3	3
Strasbourg	3104	20	5	2	13	0.033	0.1	3	4
1 other		1	-	-	1				
HOLLAND									
Zwijndrecht	4108	3	1	-	2	0.1	0.1	7	12
Oost-Soubourg	4119	2	2	-	-	0.25	0.1	15	16
FINLAND									
Jokioinen	8121	53	32	1	-	0.1	0.1	7	4
SWEDEN									
Uppsala	?	82	63	17	2	Not known		7	5
MALTA	2541	4	1	3	-	0.01	0.05	3	6
Totals		534	387	79	70				

NOTES σ_A, σ_T are the assumed angular and time accuracies

σ_{dec} (before) = $\{\sigma_A^2 + (0.43\ \sigma_T)^2\}^{\frac{1}{2}}$ expressed in minutes of arc

σ_{dec} (after) = rms of declination residuals

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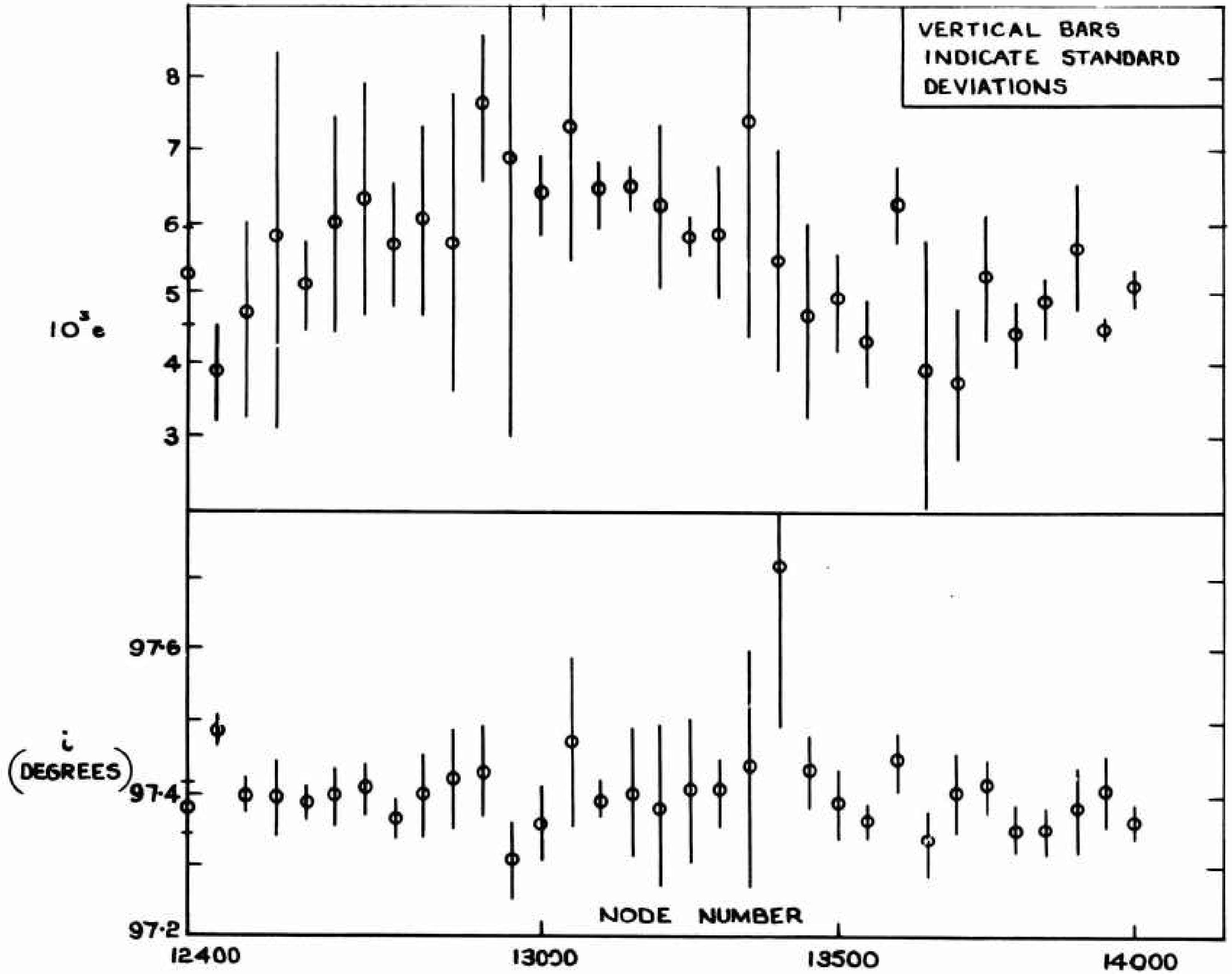

FIG. 1 VALUES OF ECCENTRICITY e AND ORBITAL INCLINATION i

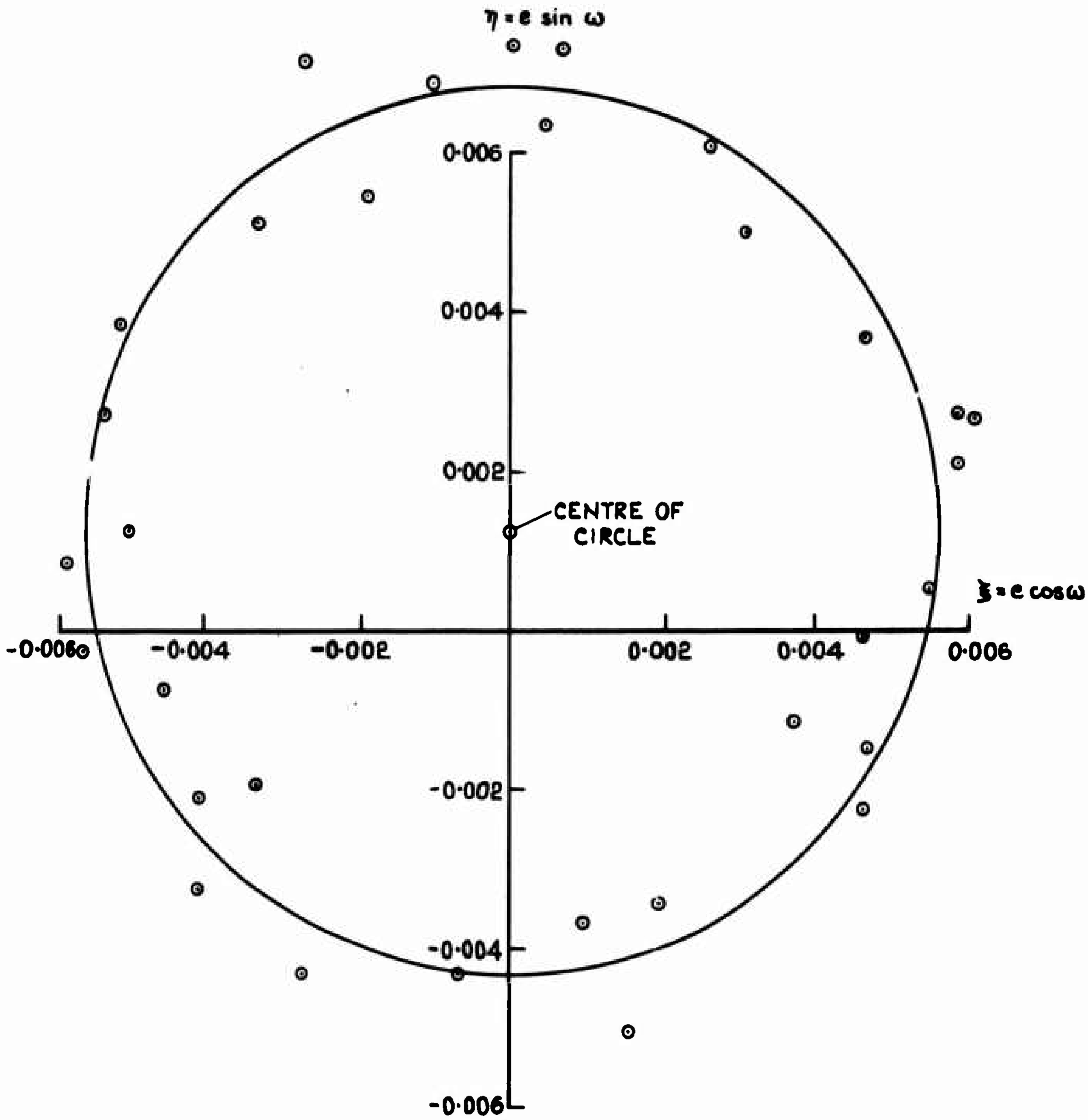

FIG. 2 VALUES OF $\xi = e \cos \omega$ AND $\eta = e \sin \omega$, WITH CIRCLE OF RADIUS 0·0056 CENTRED AT (0, 0·00125)

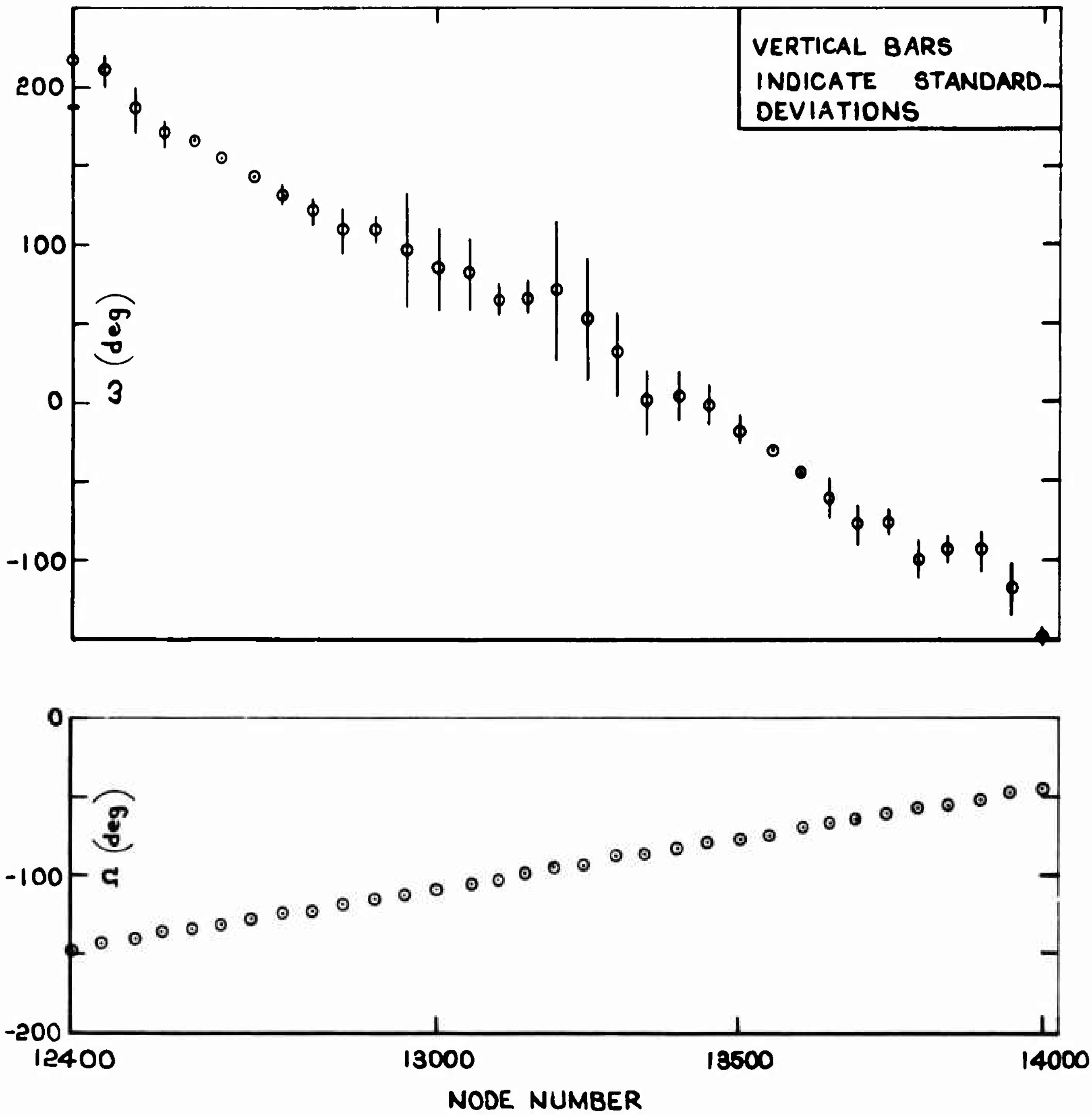

FIG. 3 VALUES OF ARGUMENT OF PERIGEE, ω, AND R.A. OF NODE, Ω

Fig.4

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SAMOS 2 FOR 1963

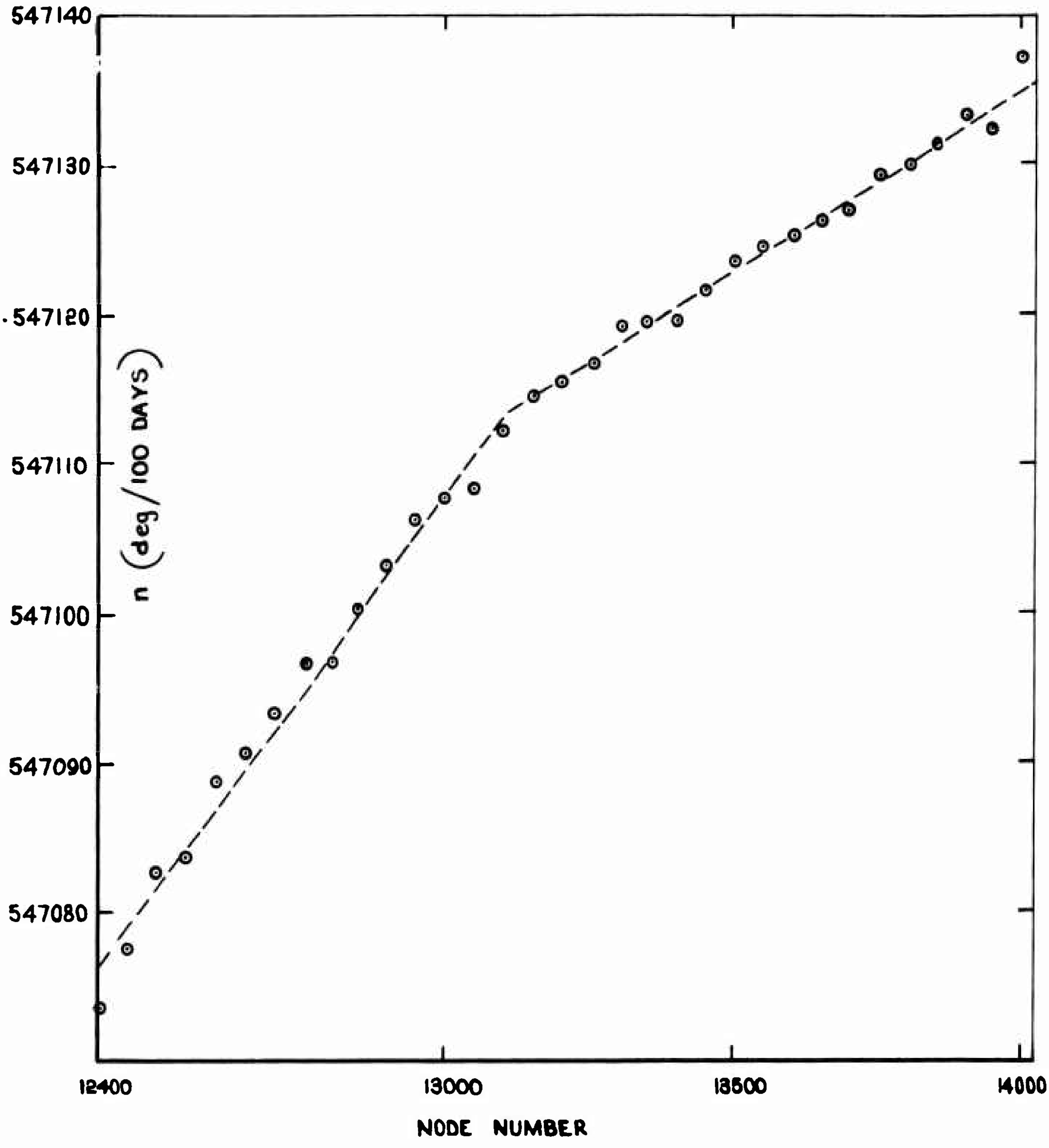

FIG. 4 VALUES OF THE MEAN MOTION n